Abstract

In DC to AC power conversion, voltage source inverters (VSI) based current controllers are usually preferred for today's high performance AC drive which requires excellent dynamic and steady state performances at different transient and load conditions, with the additional advantages like inherent short circuit and over current protection. Out of different types of current controllers, hysteresis controllers are widely used due to their simplicity and ability to meet the requirements for a high performance AC drives. But the conventional hysteresis controllers suffers from wide variation of PWM switching frequency, overshoot in current errors, sub-harmonic components in the current waveform and non-optimum switching at different operating point of the drive system. To mitigate these problems, particularly to control the switching frequency variation, which is the root cause of all other problems, several methodologies like ramp comparison based controller, predictive current controller, etc. were proposed in the literature. But amplitude and phase offset error in the ramp comparison based controllers and complexities involved in the predictive controllers have limited the use of these controllers. Moreover, these type of controllers, which uses three separate and independently controlled tolerance band (sinusoidal type or adaptive) to control the 3-phase currents, shows limited dynamic responses and they are not simple to implement. To tackle the problem of controlling 3-phase currents simultaneously, space vector based hysteresis current controller is very effective as it combines the current errors of all the three phases as a single entity called current error space vector. It has a single controller's logic with a hysteresis boundary for controlling this current error space vector. Several papers on space vector based hysteresis controllers for 2-level inverter with constant switching frequency have been published, but the application of the constant switching frequency based hysteresis current controllers for multi-level inverter fed drive system, has not been addressed properly. Use of multi-level inverter in modern high performance drive for medium and high voltage levels is more prominent because of multi-level's inherent advantages like good power quality, good electromagnetic compatibility (EMC), better DC link voltage utilization, reduced device voltage rating, so on. Even though some of the earlier works describe three-level space vector based hysteresis current controller techniques, they are specific to the particular level of inverters and does not demonstrate constant switching frequency of operation. This thesis proposes a novel approach where nearly constant

switching frequency based hysteresis controller can be implemented for any general n-level inverter and it is also independent of inverter topology. In this work, varying parabolic boundary is used as the hysteresis current error boundary for controlling the current in a multi-level space vector structure. The computation of the parabolic boundary is accomplished offline and all the necessary boundary parameters at different operating points are stored in the look-up tables. The varying parabolic boundary for the multi-level space vector structure depends on the sampled reference phase voltage values which are estimated from stator current error information and then using the equivalent circuit model of induction motors. Here, a mapping technique is adopted to bring down all the three phase references to the inner- most carrier region, which results in mapping any outer triangular structure where tip of the voltage space vector is located, to one of the sectors of the inner most hexagon of the multi-level space vector structure. In this way, the required *mapped sector* information is easily found out to fix the correct orientation of the parabolic boundary in the space vector plane. This mapping technique simplifies the controller's logic similar to that of a 2-level inverter. For online identification of the inverter switching voltage vectors constructing the present outer triangle of the multi-level space vector structure, the proposed controller utilizes the sampled phase voltage references. This identification technique is novel and also generic for any n-level inverter structure. This controller is having all the advantages of a space vector based hysteresis current controller and that of a multi-level inverter apart from having a nearly constant switching frequency spectrum similar to that of a voltage controlled space vector PWM (VC-SVPWM).

Using the proposed controller, simulation study of a five-level inverter fed induction motor (IM) drive scheme, was carried out using Matlab-Simulink. Simulation study showed that the switching frequency variations in a fundamental cycle and over the entire speed range of the linear modulation region, is similar to that of a VC-SVPWM based multi-level VSI. The proposed hysteresis controller is experimentally verified on a 7.5 kW IM vector control drive fed with a five-level VSI. The proposed current error space vector based hysteresis controller providing nearly constant switching frequency is implemented on a TI TMS320LF2812 DSP and Xilinx XC3S200FT256 FPGA based platform. The three-phase reference currents are generated depending on the frequency command and the controller is tested with the drive for the entire operating speed range of the machine in forward and reverse directions. Steady state and quick transient results of the proposed drive are presented in this thesis.

This thesis also proposes another type of hysteresis controller, firstly for 2-level inverter and then for general n-level multi-level inverter, which eliminates the parabolic boundary and replaces it with a boundary which is computed online and does not use any look up table for boundary selection. The current error boundary for the proposed hysteresis controller is computed online in a very simple way, using the information of estimated fundamental stator voltages along α and β axes of space vector plane. The method adopted for the proposed controller to compute the boundary does not involve any complicated computations and it selects the optimal vector for switching when current error space vector crosses the boundary. This way adjacent voltage vector switching similar to VC-SVPWM can be ensured. For 2-level inverter, it precisely determines the sector, in which reference voltage vector is present. In multi-level inverter, this controller also finds out the mapped sector information using the same mapping techniques as explained in the first part of this thesis. In both 2-level and multi-level inverter, the proposed controller does not use any look up table for finding individual voltage vector switching times from the estimated voltage references. These switching times are used for the computation of hysteresis boundary for individual vectors. Thus the hysteresis boundary for individual vectors is exactly calculated and the boundary is similar to that of VC-SVPWM scheme for the respective levels of inverter. In the present scheme, the phase voltage harmonic spectrum is very close to that of a constant switching frequency VC-SVPWM inverter. In this thesis, at first, the proposed on line boundary computation scheme is implemented for a 2-level inverter based controller for the initial study, so that it can be executed as fast as 10 μs in a DSP platform, which is required for accurate current control. Then the same algorithm of 2-level inverter is extended for multi-level inverter with the additional logic for online identification of nearest switching voltage vectors (also used in the parabolic boundary case) for the present sampling interval. Previously mentioned mapping technique for multi-level inverter, is also implemented here to bring down the phase voltage references to the inner-most carrier region to realize the multi-level current control strategy equivalent to that of a 2-level inverter PWM current control.

Simulation study to verify the steady state as well as transient performance of the proposed controller for both 2-level as well as five-level VSI fed IM drive is carried out using Simulink tool box of MATLAB Simulation Software. The proposed hysteresis controllers are experimentally verified on a 7.5 kW IM vector control drive fed with a two-level VSI and five-level VSI separately. The proposed current error space vector based hysteresis controller providing nearly constant switching frequency profile for phase voltage is implemented on the TI TMS320LF2812 DSP and Xilinx XC3S200FT256 FPGA based platform. The three-phase reference currents are generated depending on the frequency command and the proposed hysteresis controllers are tested with drive for the entire operating speed range of the machine in forward and reverse directions. Steady state and transient results of the proposed drive are also presented for different operating conditions, through the simulation study followed by experimental verifications. Even though the simulation and experimental verifications are done on a 5-level inverter to explain the proposed hysteresis controller, it can be easily implemented for any general n-level inverter, as described in this thesis.